Findings of Abdominal Imaging in Patients with COVID-19 – Part 1: Hollow Organs

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Abstract

Since COVID-19 has spread worldwide, the role of imaging for early detection of the disease has become more prominent. Abdominal symptoms in COVID-19 are common in addition to respiratory manifestations. This review collected the available data about abdominal computed tomography (CT) and ultrasonography indications in hollow abdominal organs in patients with COVID-19 and their findings. Since abdominal imaging is less frequently used in COVID-19, there is limited information about the gastrointestinal findings. The most common indications for abdominal CT in patients with COVID-19 were abdominal pain and sepsis. Bowel wall thickening and fluid-filled colon were the most common findings in abdominal imaging. Acute mesenteric ischemia (AMI) was one of the COVID-19 presentations secondary to coagulation dysfunction. AMI manifests with sudden abdominal pain associated with high morbidity and mortality in admitted patients; therefore, CT angiography should be considered for early diagnosis of AMI. Ultrasonography is a practical modality because of its availability, safety, rapidity, and ability to be used at the bedside. Clinicians and radiologists should be alert to indications and findings of abdominal imaging modalities in COVID-19 to diagnose the disease and its potentially serious complications promptly.

Keywords:
COVID-19, Abdominal, Imaging, Computed tomography, Ultrasonography

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Introduction

In December 2019, a group of pneumonia cases infected with a novel beta coronavirus was reported in Wuhan, China.[1] Later renamed severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), this pathogen resulted in a global pandemic called COVID-19.[2] As of October 2021, nearly 234 million people have been contaminated with COVID-19, and 4.7 million have died.[3] COVID-19 is notorious as a respiratory disease presenting with fever, cough, fatigue, and dyspnea[2]; however, respiratory manifestations might overshadow other systemic involvements such as gastrointestinal (GI) symptoms. It has been discovered that as high as 17% of patients with COVID-19 have GI symptoms.[4,5] Anorexia, diarrhea, vomiting, and abdominal pain are the most reported GI manifestations and are frequently presented in patients with a prolonged course of illness or admission to the intensive care unit (ICU).[6,7] Additionally, GI

symptoms might be apparent in the initial presentation of patients with COVID-19 infection.[8]

Spike (S) protein of SARS-Cov-2 attaches to the angiotensin-converting enzyme 2 (ACE II) receptor and enters the cells via this connection.[1] ACE II receptor is produced on pulmonary epithelial cells, gastrointestinal, vascular endothelium, and other tissues.[9] Recent studies have shown that abdominal imaging findings can help diagnose different manifestations of an atypical COVID-19 with GI involvement.[10]

Cross-sectional abdominal imaging modalities are not used routinely in COVID-19.[11] The definite diagnosis of COVID-19 is primarily based on laboratory viral RNA testing of samples from the upper respiratory tract, and it is widely available.[10] In the early approach in COVID-19 patients with respiratory symptoms, a chest computed tomography (CT) is a valuable modality to control the pandemic.[12] Still, in patients with a severe and atypical GI manifestation of COVID-19, cross-sectional abdominal imaging can be utilized to detect severe disease complications more quickly and start treatment as soon as possible.[10] According to prior findings, on abdominal CT, 65% of patients with COVID-19 had ground-glass opacities at the base of the lungs. Patients with negative PCR are more likely to exhibit GI abnormalities on CT images.[13] Abdominal pain and sepsis were the most reported indications for abdominal CT in SARS-CoV-2 infection.[14,15] Moreover, other symptoms like diarrhea, nausea, vomiting, abdominal distention, and GI bleeding also warranted an abdominal CT in previous studies.[10,14-16] Contrast-enhanced abdominopelvic CT is a fast fundamental imaging modality to identify ischemic bowel disease, which happens secondary to the hypercoagulable state in severe conditions.[17] In COVID-19 patients with major GI complaints, contrast-enhanced abdominopelvic CT should be considered, especially in ICU admitted cases. Radiologists should be familiar with the potential imaging features of COVID-19 on abdominal CT.[10,18]

Ultrasonography is an available, accurate, safe, and quick imaging technique that can be performed at frequent intervals to address relevant clinical questions without using ionizing radiation.[19] Another advantage of ultrasonography is the point of care ultrasound (POCUS). Whenever performing a CT, it is necessary to ambulate the patient to the radiology department. At the same time, POCUS has been applied in emergency departments and ICUs at the bedside.[20] Abdominal pain and abnormal liver function tests are the main indications of ultrasonography in COVID-19.[21] Contrast-enhanced ultrasonography (CEUS) is progressively used globally and has a pivotal diagnostic role in COVID-19 infections. If CEUS is to be performed straight at the bedside of ICU patients, expert technicians/physicians are required. CEUS can be an essential modality to assess capillary perfusion of abdominal organs and imminent kidney failure in severe cases of COVID-19.[22]

This review aims to determine the latest available data related to abdominal CT and ultrasonography applications and their corresponding findings in COVID-19 infection based on the involvement of hollow abdominal viscera. Our goal is to help clinicians achieve greater awareness to identify the variety of GI presentations associated with COVID-19.

Bowel

Gastric and duodenal glandular cells, epithelial and endothelial cells of the rectum, and small intestinal enterocytes are the usual sites in the bowel where the ACE-2 receptor is expressed and become commonly infected by SARS-CoV-2.[23]

On CT images, bowel findings include a contrast-enhanced fluid-filled colon, luminal distention, bowel wall thickening, mucosal hyperenhancement, peri enteric fat stranding, mesenteric inflammation, vascular engorgement, pneumatosis, and portal venous gas[15,16,24,25] The most frequently described imaging features are bowel wall thickening and fluid-filled colon without wall thickening.[24] These findings are most often seen in patients admitted to the ICU and are not associated with age, sex, or GI symptoms upon admission.[14] Thickening of the small bowel wall and hyperenhancement of the mucosa are attributed to the direct inflammatory effect of the SARS-Cov-2.[16] Moreover, hyperemia and edema of the colonic wall are well-matched to the diagnosis of acute colitis, which can also be related to the direct or indirect effect of the infection (Figure 1).[10]

Other infrequent manifestations such as pneumoperitoneum, acute diverticulitis, ileus, GI

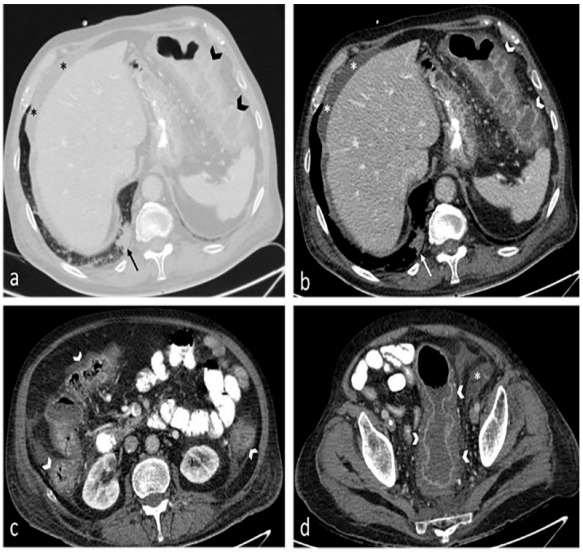

Figure 1. Acute pan colitis in a 74-year-old man with COVID-19 pneumonia. Axial CT images (a, b) demonstrate a subpleural patchy air space opacity (black and white arrows) at the right lower lobe suggestive of pneumonia. Axial CT images (a, b, c, d) also reveal diffuse concentric mural thickening and submucosal edema of the colon associated with adjacent pericolic fat stranding (white and black arrowheads) consistent with pan colitis. Mild free fluid is also evident in the peritoneal cavity (white and black asterisks).

perforation, notable ascites, and intramural bowel gas, also known as pneumatosis intestinalis, can be visualized in patients with COVID-19 (Figure 2).[26-28] Pneumatosis and portal venous gas are considered a hallmark of mesenteric ischemia, a condition that occurs commonly in severely ill patients. Although, various other etiologies, such as viral intestinal infection and positive-pressure ventilation, can lead to this phenomenon.[14,16,18]

Vadvala and colleagues have reported periportal edema and hematomas at the retroperitoneum, abdominal wall, and rectosigmoid in CT angiography of critically ill patients with COVID-19.[27] A case report showed an adult patient with COVID-19 who presented with small bowel obstruction, cecal wall thickening, and ileocolonic intussusception, without masses, on an abdominal CT.[29] A summary of bowel imaging findings is presented in Table 1.

Ultrasonography is a modality that can be done to examine the abdomen in COVID-19. Ileocolic intussusception is an uncommon ultrasound manifestation reported in COVID-19 pediatric cases (Table 2).[30]

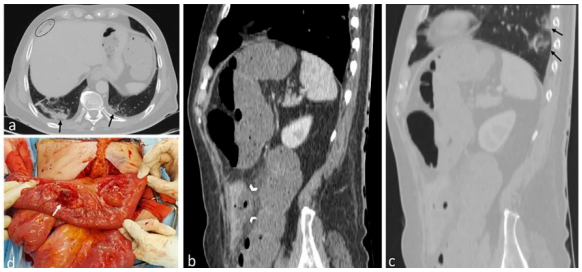

Figure 2. Perforated jejunal diverticulitis in a 72-year-old man with COVID-19 infection. Axial and sagittal CT images (a, c) show bilateral subpleural airspace opacities (black arrows) at the lower thoracic level. Subdiaphragmatic gas bubbles are noted (black oval) consistent with pneumoperitoneum. Sagittal CT image (b) reveals a small outpouching of the jejunum (white arrowheads) associated with mural edema and notable adjacent fat inflammation in keeping with perforated acute jejunal diverticulitis. Intraoperative photograph (d) demonstrates a perforated jejunal diverticulum (white arrow).

Despite an increased number of complicated acute appendicitis during the pandemic, there is no definite association between acute appendicitis and COVID-19.[8] It has been claimed that a viral infection might cause appendicitis by multiple mechanisms, including lymphatic hyperplasia and mucosal ulceration, which can lead to appendix blockage and secondary bacterial infection, respectively.[8]

A well-known pediatric complication of COVID-19, which could present signs and symptoms similar to appendicitis, is a multisystem inflammatory syndrome in children (MIS-C).[31] Fenlon Iii et al found that owing to non-specific imaging appearances, the diagnosis of MIS-C related to COVID-19 was based on clinical manifestations rather than pure imaging findings.[32] MIS-C can be differentiated from appendicitis when Kawasaki-like presentations such as mucocutaneous symptoms are present.[33] In the reported cases of MIS-C with a chief complaint of right lower quadrant pain who underwent the ultrasonography, findings included a non-compressible and dilated appendix with mural hyperemia, periappendiceal mesenteric fat stranding and edema, ascites, and thickened terminal ileum.[32-34] On CT images, findings of MIS-C-related appendicitis consist of luminal dilatation, wall thickening of the appendix and colon, calcified deposit within the appendix, pelvic free fluid, enlarged lymph nodes, and perforation with adjacent small rim-enhancing fluid collections (Figures 3 and 4)[33,34] Imaging

Table 1. Abnormal abdominal imaging features of bowel reported in CT of patients with COVID-19 in previous studies

Studies	Abdominal imaging features of bowel			
Bhayana et al[14]	BWT	perforated small bowel		
Kanne et al[35]	BWT	Fluid filled bowel		
Horvat et al [16]	BWT	Intestinal distention	Mucosal hyperenhancement suggestive of adynamic ileus	
Hellinger et al[36]	BWT	Fluid filled bowel	Small-bowel mucosal hyperemia	
Carvalho et al[37]	BWT	Mural hyperenhancement	Pericolic fat stranding	
Sattar et al [38]	BWT	Colonic ileus with air-fluid levels		
Guo et al[39]	Segmental bowel wall swelling			
Jaijakul [40]	BWT			
Behzad et al [25]	Fluid filled bowel	Postcontrast mural hyper enhancement	Mild to moderate nonspecific pericolic fat stranding	
Tirumani et al[15]	Fluid filled bowel	Diarrhea	GI bleeding	
Goldberg-Stein et al[41]	BWT			
Vadvala et al[27]	Hematomas at retroperitoneum, abdominal wall, and rectosigmoid			
Morparia et al[34]	BWT			
Boraschi et al[24]	Hyperemic BWT	Distension of the bowel	Free fluid between the intestinal loops with associated diffuse subcutaneous edema	Perivisceral fat edema
Lui et al[26]	BWT	Fluid-filled colon Pneumatosis	pneumoperitoneum intussusception	ascites
Funt et al[13]	BWT	Mild peri-enteric fat stranding		
Palacios et al[42]	BWT	Pneumatosis on a non-enhancing segment of the jejunum	A defect in the lateral wall of the jejunum and adjacent localized collection of intraperitoneal gas	
Farina et al[43]	Dilated small intestinal loops	Air-fluid levels in small intestinal loops	Thinning of the small bowel walls and absence of contrast enhancement indicating ischemia	
Vaidya et al[44]	BWT	Distal ileal loops with non-enhancing, barely visible walls suggestive of bowel ischemia		
Miyara et al[45]	Bowel dilatation	Small bowel and cecal pneumatosis	Portal, splenic, and mesenteric vein gas	
Thuluva et al[46]	BWT with contrast enhancement			

BWT, Bowel wall thickening; GI, Gastrointestinal.

Table 2. Ultrasound findings of COVID-19 patients with intussusception in previous studies

Studies	Publication type	Gender	Age	Symptoms	Abdominal Ultrasonography features
Athamnah et al[30]	Case report	Male	6 mon	Vomiting, constipation, Rectal bleeding, distension of abdomen	Ileocolic intussusception (Target sign)
Rajalakshmi et al[47]	Case report	Male	8 mon	Fever, vomiting, Rectal bleeding	Ileocolic intussusception in the subxiphoid region
Bazuaye-Ekwuyasi et al[48]	Case report	Male	9 mon	Agitation, fever, congestion, cough, and sneezing	Concentric alternating echogenic and hypoechoic bands, consistent with the target sign of intussusception

findings of appendiceal involvement in COVID-19 are summarized in Table 3.

Vasculopathy

Thromboembolic complications are being increasingly encountered in patients with COVID-19 pneumonia.[50] Coagulation dysfunction is related to multiple factors such as inflammation, endothelial and platelet dysfunction, as well as blood stasis.[51] COVID-19 may influence endothelial cells by infecting them directly

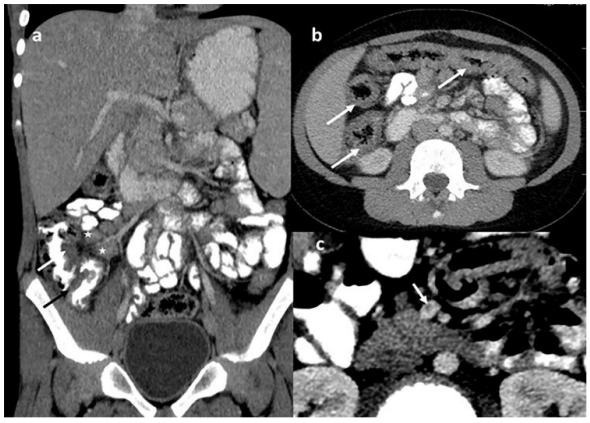

Figure 3. Multisystem inflammatory syndrome in children (MIS-C) in a 9-year-old boy presented with abdominal pain, nausea, vomiting, and fever 3 weeks after being infected with SARS-CoV-2 virus. Coronal(a) and axial (b) contrast-enhanced CT images show hepatosplenomegaly, mesenteric lymphadenopathies (white stars in a), and wall thickening of terminal ileum (black arrow), cecum, ascending and transverse colon (black arrows). 4 days after admission, the patient experienced abdominal pain again. Axial CT image (c) demonstrates partial thrombosis (white arrow in c) within the superior mesenteric vein (SMV).

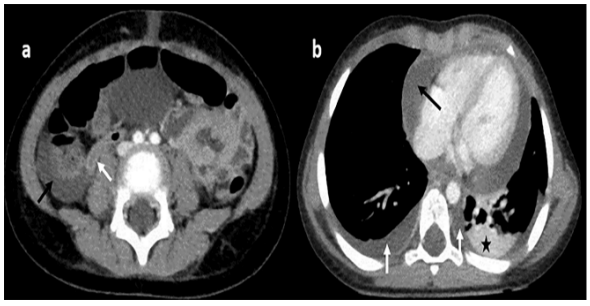

Figure 4. Multisystem inflammatory syndrome in children (MIS-C) in a 2-year-old girl presented with fever, abdominal pain, and shortness of breath 3 weeks after infection with SARS-CoV-2 virus. Axial CT image (a) reveals mild free fluid in the right lower quadrant (RLQ) and appendix wall hyperenhancement with normal luminal diameter containing air bubbles (black and white arrows, respectively). In lower thoracic levels (b), pericardial effusion (black arrow), bilateral pleural effusion (white arrows), and consolidation in the lower lobe of the left lung (black star) are depicted.

via ACE2 receptors.[51] Goshua and colleagues have shown that the severity and mortality of COVID-19 are associated with endothelial damage.[52] The virus activates complement proteins uncontrollably, responsible for acute and chronic inflammation, endothelial cell dysfunction, arterial and venous thrombus development, and intravascular coagulation. The activation of the complement cascade results in acute stroke, acute myocardial infarction, extracorporeal membrane oxygenation circuit thrombosis, multiple organ failure, and death.[53-55]

Thromboembolic complications are a leading cause of morbidity and mortality in admitted patients with COVID-19, even in patients receiving anticoagulation therapy.[56] Microvascular involvement mainly appears as end-organ ischemia on abdominal imaging, including bowel loops, spleen, kidneys, and liver infarctions.[35] Superior mesenteric artery (SMA) thrombotic occlusion, rarely reported, gives rise to intestinal gangrene, presented as dilated ileal loops with non-enhancing, barely discernible walls on contrast-enhanced CT.[35,44] Direct viral infection, small vessel thrombosis, and non-occlusive mesenteric ischemia have been proposed as the underlying causes of a wide range of intestinal manifestations in COVID-19.[14,35] In severe cases, deep venous thrombosis, acute pulmonary thromboembolism, and AMI have been described.[14,50]

CT angiography (CTA) should be performed immediately in patients with COVID-19 with sudden abdominal pain for early diagnosis of AMI.[18] Emboli tend to involve SMA because of the slight branching angle at the origin, compared with celiac and inferior mesenteric arteries.[57] On abdominal CT, specific imaging findings, including intramural bowel gas, absence of bowel wall enhancement, hepatic portal venous gas, and ischemia of other organs, favor a diagnosis of SMA or superior mesenteric vein (SMV) thrombosis.[58]

Table 3. CT findings of patients with COVID-19 with appendiceal involvement in previous studies

Studies	Abdominal imaging features of appendix				
Morparia et al[34]	Appendiceal dilation	Mural thickening of the appendix			
Anderson et al[33]	Appendiceal dilation	Mural thickening of the appendix	Calcified deposit within the appendix	Appendiceal perforation	Several small rim-enhancing fluid collections around the appendix
Samies et al[49]	Enlarged appendix suggestive of uncomplicated appendicitis				

Table 4. CT findings of COVID-19 patients with vascular involvement in previous studies

Studies	Abdominal imaging features of vasculopathy	
Boraschi et al[24]	Fat stranding surrounding the mesenteric vessels	
Vaidya et al[44]	Hypoperfused distal SMA[1] branches (i.e., the ileocolic and right colic branches) consistent with SMA thrombosis	
Bhayana et al[14]	Mesenteric congestion	Gas in the transverse mesocolon vasculature
Thuluva et al[46]	A significant filling defect in the superior mesenteric vein in keeping with thrombosis	
Abdelmohsen et al[56]	Psoas muscle hemorrhage with contrast extravasation suggestive of active bleeding in CT angiography	Pelvic extraperitoneal hemorrhage presenting centers of active bleeding in CT angiography
Nakamura et al[59]	Massive right iliopsoas muscle hematoma with extravasation extending to the retroperitoneal area in CECT[2]	A small low-density area in the left iliopsoas muscle suggestive of a hematoma
Angileri et al[60]	Spontaneous iliopsoas muscle hematoma	

SMA, superior mesenteric artery; CECT, Contrast-enhanced computed tomography

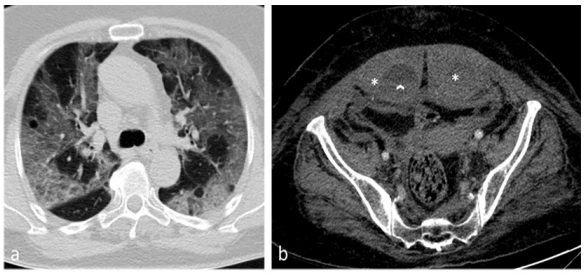

Figure 5. Rectus sheath hematoma in a 69-year-old woman with COVID-19 pneumonia. Axial chest CT (a) demonstrates confluent geographic areas of ground-glass opacity with the dominant peripheral distribution. Axial CT (b) shows bilateral rectus sheath hematoma (white asterisks) with fluid-fluid level formation (arrowhead) on the right side.

In addition, other findings such as non-occlusive AMI, thrombosis of distal SMA branches, and thromboembolic occlusion of SMA have been reported.[18] AMI could present with decreased peristalsis, interloop fluid, and increased intraluminal contents indicating stasis in the US exam.[44] on abdominal CT, SMV thrombosis was reported with a filling defect in the SMV, diffuse small bowel wall thickening, and mesenteric fat stranding attributed to mesenteric venous congestion.[46]

Besides hypercoagulation frequently seen in patients with COVID-19, bleeding may also occur and is associated with high mortality and morbidity in severe cases.[56] In plenty of case reports, intra-abdominal hemorrhage, especially extraperitoneal and intramuscular hematomas in the iliopsoas and rectus sheet, was perceived in abdominal CTA/CTV, with or without active bleeding.[56,59,60] In some cases, the extraperitoneal hemorrhage demonstrated internal blood fluid levels in non-contrast CT images, indicative of a hyperdense fresh hematoma (Figure 5).[56] Vascular abnormalities reported in patients with COVID-19 are presented in Table 4.

Conclusion

GI manifestations are common among patients with COVID-19, particularly in severely ill patients. Bowel pathologies are commonly visualized on abdominal CT in patients with COVID-19 and are associated with worse outcomes. Owing to the poor prognosis of some bowel abnormalities such as AMI, clinicians should consider it whenever intestinal signs/symptoms are present. Abdominal CT and ultrasonography must be applied to help clinicians identify any organ involvement quickly. At the same time, radiologists should be vigilant about imaging characteristics of abdominal pathologic conditions in COVID-19 to reach a diagnosis promptly. Considering that in many patients with COVID-19, the only clinical sign/symptom is related to the GI system, it is suggested to expand the scan field to include the base of the lungs when performing abdominal CT.

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Ethical Approval

There is nothing to be declared.

Conflict of Interest

The authors declare no conflict of interest related to this work.

References

1. Wu F, Zhao S, Yu B, Chen YM, Wang W, Song ZG, et al. A new coronavirus associated with human respiratory disease in China. *Nature* 2020;579(7798):265-9. doi: 10.1038/s41586-020-2008-3
2. Alturki SO, Alturki SO, Connors J, Cusimano G, Kutzler MA, Izmirly AM, et al. The 2020 pandemic: current SARS-CoV-2 vaccine development. *Front Immunol* 2020;11:1880. doi: 10.3389/fimmu.2020.01880
3. Johns Hopkins Corona Virus Resource Center Maps and Trends. Available from: https://coronavirus.jhu.edu/map.html.
4. Cheung KS, Hung IFN, Chan PPY, Lung KC, Tso E, Liu R, et al. Gastrointestinal manifestations of SARS-CoV-2 infection and virus load in fecal samples from a Hong Kong cohort: systematic review and meta-analysis. *Gastroenterology* 2020;159(1):81-95. doi: 10.1053/j.gastro.2020.03.065
5. Barkmeier DT, Stein EB, Bojicic K, Otemuyiwa B, Vummidi D, Chughtai A, et al. Abdominal CT in COVID-19 patients: incidence, indications, and findings. *Abdom Radiol (NY)* 2021;46(3):1256-62. doi: 10.1007/s00261-020-02747-5
6. Redd WD, Zhou JC, Hathorn KE, McCarty TR, Bazarbashi AN, Thompson CC, et al. Prevalence and characteristics of gastrointestinal symptoms in patients with severe acute respiratory syndrome coronavirus 2 infection in the United States: a multicenter cohort study. *Gastroenterology* 2020;159(2):765-7.e2. doi: 10.1053/j.gastro.2020.04.045
7. Tian Y, Rong L, Nian W, He Y. Review article: gastrointestinal features in COVID-19 and the possibility of faecal transmission. *Aliment Pharmacol Ther* 2020;51(9):843-51. doi: 10.1111/apt.15731
8. Abdalhadi A, Alkhatib M, Mismar AY, Awouda W, Albarqouni L. Can COVID 19 present like appendicitis? *IDCases* 2020;21:e00860. doi: 10.1016/j.idcr.2020.e00860
9. Salamanna F, Maglio M, Landini MP, Fini M. Body localization of ACE-2: on the trail of the keyhole of SARS-CoV-2. *Front Med (Lausanne)* 2020;7:594495. doi: 10.3389/fmed.2020.594495
10. Shiralkar K, Chinapuvvula N, Ocazionez D. Cross-sectional abdominal imaging findings in patients with COVID-19. *Cureus* 2020;12(8):e9538. doi: 10.7759/cureus.9538
11. Basara Akin I, Altay C, Eren Kutsoylu O, Secil M. Possible radiologic renal signs of COVID-19. *Abdom Radiol (NY)* 2021;46(2):692-5. doi: 10.1007/s00261-020-02671-8
12. Radmard AR, Gholamrezanezhad A, Montazeri SA, Kasaeian A, Nematollahy N, Molaee Langrudi R, et al. A multicenter survey on the trend of chest CT scan utilization: tracing the first footsteps of COVID-19 in Iran. *Arch Iran Med* 2020;23(11):787-93. doi: 10.34172/aim.2020.105
13. Funt SA, Cohen SL, Wang JJ, Sanelli PC, Barish MA. Abdominal pelvic CT findings compared between COVID-19 positive and COVID-19 negative patients in the emergency department setting. *Abdom Radiol (NY)* 2021;46(4):1498-505. doi: 10.1007/s00261-020-02796-w
14. Bhayana R, Som A, Li MD, Carey DE, Anderson MA, Blake MA, et al. Abdominal imaging findings in COVID-19: preliminary observations. *Radiology* 2020;297(1):E207-E15. doi: 10.1148/radiol.2020201908
15. Tirumani SH, Rahnemai-Azar AA, Pierce JD, Parikh KD, Martin SS, Gilkeson R, et al. Are asymptomatic gastrointestinal findings on imaging more common in COVID-19 infection? Study to determine frequency of abdominal findings of COVID-19 infection in patients with and without abdominal symptoms and in patients with chest-only CT scans. *Abdom Radiol (NY)* 2021;46(6):2407-14. doi: 10.1007/s00261-020-02920-w
16. Horvat N, Pinto PVA, Araujo-Filho JAB, Santos J, Dias AB, Miranda JA, et al. Abdominal gastrointestinal imaging findings on computed tomography in patients with COVID-19 and correlation with clinical outcomes. *Eur J Radiol Open* 2021;8:100326. doi: 10.1016/j.ejro.2021.100326
17. Singh B, Kaur P. COVID-19 and acute mesenteric ischemia: a review of literature. *Hematol Transfus Cell Ther* 2021;43(1):112-6. doi: 10.1016/j.htct.2020.10.959
18. Keshavarz P, Rafiee F, Kavandi H, Goudarzi S, Heidari F, Gholamrezanezhad A. Ischemic gastrointestinal complications of COVID-19: a systematic review on imaging presentation. *Clin Imaging* 2021;73:86-95. doi: 10.1016/j.clinimag.2020.11.054
19. Kumar S, Kumar A, Goel P, Vyas S, Baitha U, Wig N. Use of ultrasonography in COVID-19: probing for success. *J Family Med Prim Care* 2020;9(8):3863-6. doi: 10.4103/jfmpc.jfmpc_764_20
20. Gandhi D, Jain N, Khanna K, Li S, Patel L, Gupta N. Current role of imaging in COVID-19 infection with recent recommendations of point of care ultrasound in the contagion: a narrative review. *Ann Transl Med* 2020;8(17):1094. doi: 10.21037/atm-20-3043
21. Balaban DV, Baston OM, Jinga M. Abdominal imaging in COVID-19. *World J Radiol* 2021;13(7):227-32. doi: 10.4329/wjr.v13.i7.227
22. Jung EM, Stroszczynski C, Jung F. Contrast enhanced ultrasonography (CEUS) to detect abdominal

microcirculatory disorders in severe cases of COVID-19 infection: first experience. *Clin Hemorheol Microcirc* 2020;74(4):353-61. doi: 10.3233/ch-209003
23. Lai CC, Ko WC, Lee PI, Jean SS, Hsueh PR. Extra-respiratory manifestations of COVID-19. *Int J Antimicrob Agents* 2020;56(2):106024. doi: 10.1016/j.ijantimicag.2020.106024
24. Boraschi P, Giugliano L, Mercogliano G, Donati F, Romano S, Neri E. Abdominal and gastrointestinal manifestations in COVID-19 patients: is imaging useful? *World J Gastroenterol* 2021;27(26):4143-59. doi: 10.3748/wjg.v27.i26.4143
25. Behzad S, Aghaghazvini L, Radmard AR, Gholamrezanezhad A. Extrapulmonary manifestations of COVID-19: radiologic and clinical overview. *Clin Imaging* 2020;66:35-41. doi: 10.1016/j.clinimag.2020.05.013
26. Lui K, Wilson MP, Low G. Abdominal imaging findings in patients with SARS-CoV-2 infection: a scoping review. *Abdom Radiol (NY)* 2021;46(3):1249-55. doi: 10.1007/s00261-020-02739-5
27. Vadvala HV, Shan A, Fishman EK, Gawande RS. CT angiography of abdomen and pelvis in critically ill COVID-19 patients: imaging findings and correlation with the CT chest score. *Abdom Radiol (NY)* 2021;46(7):3490-500. doi: 10.1007/s00261-021-03164-y
28. Meini S, Zini C, Passaleva MT, Frullini A, Fusco F, Carpi R, et al. Pneumatosis intestinalis in COVID-19. *BMJ Open Gastroenterol* 2020;7(1):e000434. doi: 10.1136/bmjgast-2020-000434
29. Jackson KM, Sabbota AL. Right hemicolectomy for ileocolonic intussusception in an adult with active COVID-19 infection: a case report. *J Surg Case Rep* 2021;2021(6):rjab205. doi: 10.1093/jscr/rjab205
30. Athamnah MN, Masade S, Hamdallah H, Banikhaled N, Shatnawi W, Elmughrabi M, et al. COVID-19 presenting as intussusception in infants: a case report with literature review. *J Pediatr Surg Case Rep* 2021;66:101779. doi: 10.1016/j.epsc.2021.101779
31. Jackson RJ, Chavarria HD, Hacking SM. A case of multisystem inflammatory syndrome in children mimicking acute appendicitis in a COVID-19 pandemic area. *Cureus* 2020;12(9):e10722. doi: 10.7759/cureus.10722
32. Fenlon Iii EP, Chen S, Ruzal-Shapiro CB, Jaramillo D, Maddocks ABR. Extracardiac imaging findings in COVID-19-associated multisystem inflammatory syndrome in children. *Pediatr Radiol* 2021;51(5):831-9. doi: 10.1007/s00247-020-04929-1
33. Anderson JE, Campbell JA, Durowoju L, Greenberg SLM, Rice-Townsend SE, Gow KW, et al. COVID-19-associated multisystem inflammatory syndrome in children (MIS-C) presenting as appendicitis with shock. *J Pediatr Surg Case Rep* 2021;71:101913. doi: 10.1016/j.epsc.2021.101913
34. Morparia K, Park MJ, Kalyanaraman M, McQueen D, Bergel M, Phatak T. Abdominal imaging findings in critically ill children with multisystem inflammatory syndrome associated with COVID-19. *Pediatr Infect Dis J* 2021;40(2):e82-e3. doi: 10.1097/inf.0000000000002967
35. Kanne JP, Bai H, Bernheim A, Chung M, Haramati LB, Kallmes DF, et al. COVID-19 imaging: what we know now and what remains unknown. *Radiology* 2021;299(3):E262-E79. doi: 10.1148/radiol.2021204522
36. Hellinger JC, Sirous R, Hellinger RL, Krauthamer A. Abdominal presentation of COVID-19. *Appl Radiol* 2020;49(3):24-6.
37. Carvalho A, Alqusairi R, Adams A, Paul M, Kothari N, Peters S, et al. SARS-CoV-2 gastrointestinal infection causing hemorrhagic colitis: implications for detection and transmission of COVID-19 disease. *Am J Gastroenterol* 2020;115(6):942-6. doi: 10.14309/ajg.0000000000000667
38. Sattar Y, Connerney M, Rauf H, Saini M, Ullah W, Mamtani S, et al. Three cases of COVID-19 disease with colonic manifestations. *Am J Gastroenterol* 2020;115(6):948-50. doi: 10.14309/ajg.0000000000000692
39. Guo Y, Hu X, Yu F, Chen J, Zheng W, Liu J, et al. Abdomen CT findings in a COVID-19 patient with intestinal symptoms and possibly false negative RT-PCR before initial discharge. *Quant Imaging Med Surg* 2020;10(5):1158-61. doi: 10.21037/qims-20-463
40. Jaijakul S. Colitis as a sole presentation of SARS-CoV-2 infection: case report. *SN Compr Clin Med* 2020;2(7):879-81. doi: 10.1007/s42399-020-00346-5
41. Goldberg-Stein S, Fink A, Paroder V, Kobi M, Yee J, Chernyak V. Abdominopelvic CT findings in patients with novel coronavirus disease 2019 (COVID-19). *Abdom Radiol (NY)* 2020;45(9):2613-23. doi: 10.1007/s00261-020-02669-2
42. Palacios S, Schiappacasse G, Valdes R, Maldonado I, Varela C. COVID-19: abdominal and pelvic imaging findings: a primer for radiologists. *J Comput Assist Tomogr* 2021;45(3):352-8. doi: 10.1097/rct.0000000000001152
43. Farina D, Rondi P, Botturi E, Renzulli M, Borghesi A, Guelfi D, et al. Gastrointestinal: bowel ischemia in a suspected coronavirus disease (COVID-19) patient. *J Gastroenterol Hepatol* 2021;36(1):41. doi: 10.1111/jgh.15094
44. Vaidya T, Nanivadekar A, Patel R. Imaging spectrum of abdominal manifestations of COVID-19. *World J Radiol* 2021;13(6):157-70. doi: 10.4329/wjr.v13.i6.157
45. Miyara SJ, Becker LB, Guevara S, Kirsch C, Metz CN,

Shoaib M, et al. Pneumatosis intestinalis in the setting of COVID-19: a single center case series from New York. *Front Med (Lausanne)* 2021;8:638075. doi: 10.3389/fmed.2021.638075

46. Thuluva SK, Zhu H, Tan MML, Gupta S, Yeong KY, Cheong Wah ST, et al. A 29-year-old male construction worker from India who presented with left- sided abdominal pain due to isolated superior mesenteric vein thrombosis associated with SARS-CoV-2 infection. *Am J Case Rep* 2020;21:e926785. doi: 10.12659/ajcr.926785
47. Rajalakshmi L, Satish S, Nandhini G, Ezhilarasi S. Unusual presentation of COVID-19 as intussusception. *Indian J Pract Pediatr* 2020;22(2):236-8.
48. Bazuaye-Ekwuyasi EA, Camacho AC, Saenz Rios F, Torck A, Choi WJ, Aigbivbalu EE, et al. Intussusception in a child with COVID-19 in the USA. *Emerg Radiol* 2020;27(6):761-4. doi: 10.1007/s10140-020-01860-8
49. Samies NL, Yarbrough A, Boppana S. Pancreatitis in pediatric patients with COVID-19. *J Pediatric Infect Dis Soc* 2021;10(1):57-9. doi: 10.1093/jpids/piaa125
50. Parry AH, Wani AH, Yaseen M. Acute mesenteric ischemia in severe coronavirus-19 (COVID-19): possible mechanisms and diagnostic pathway. *Acad Radiol* 2020;27(8):1190. doi: 10.1016/j.acra.2020.05.016
51. Mokhtari T, Hassani F, Ghaffari N, Ebrahimi B, Yarahmadi A, Hassanzadeh G. COVID-19 and multiorgan failure: a narrative review on potential mechanisms. *J Mol Histol* 2020;51(6):613-28. doi: 10.1007/s10735-020-09915-3
52. Goshua G, Pine AB, Meizlish ML, Chang CH, Zhang H, Bahel P, et al. Endotheliopathy in COVID-19-associated coagulopathy: evidence from a single-centre, cross-sectional study. *Lancet Haematol* 2020;7(8):e575-e82. doi: 10.1016/s2352-3026(20)30216-7
53. Noris M, Benigni A, Remuzzi G. The case of complement activation in COVID-19 multiorgan impact. *Kidney Int* 2020;98(2):314-22. doi: 10.1016/j.kint.2020.05.013
54. Oudkerk M, Büller HR, Kuijpers D, van Es N, Oudkerk SF, McLoud T, et al. Diagnosis, prevention, and treatment of thromboembolic complications in COVID-19: report of the National Institute for Public Health of the Netherlands. *Radiology* 2020;297(1):E216-E22. doi: 10.1148/radiol.2020201629
55. Magro C, Mulvey JJ, Berlin D, Nuovo G, Salvatore S, Harp J, et al. Complement associated microvascular injury and thrombosis in the pathogenesis of severe COVID-19 infection: a report of five cases. *Transl Res* 2020;220:1-13. doi: 10.1016/j.trsl.2020.04.007
56. Abdelmohsen MA, Alkandari BM, Abdel Razek AAK, Tobar AM, Gupta VK, Elsebaie N. Abdominal computed tomography angiography and venography in evaluation of hemorrhagic and thrombotic lesions in hospitalized COVID-19 patients. *Clin Imaging* 2021;79:12-9. doi: 10.1016/j.clinimag.2021.04.002
57. Florim S, Almeida A, Rocha D, Portugal P. Acute mesenteric ischaemia: a pictorial review. *Insights Imaging* 2018;9(5):673-82. doi: 10.1007/s13244-018-0641-2
58. Al Mahruqi G, Stephen E, Abdelhedy I, Al Wahaibi K. Our early experience with mesenteric ischemia in COVID-19 positive patients. *Ann Vasc Surg* 2021;73:129-32. doi: 10.1016/j.avsg.2021.01.064
59. Nakamura H, Ouchi G, Miyagi K, Higure Y, Otsuki M, Nishiyama N, et al. Case report: iliopsoas hematoma during the clinical course of severe COVID-19 in two male patients. *Am J Trop Med Hyg* 2021;104(3):1018-21. doi: 10.4269/ajtmh.20-1507
60. Angileri SA, Petrillo M, Meglio LD, Arrichiello A, Rodà GM, Ierardi AM, et al. Adverse events in coronavirus disease patients management: a pictorial essay. *J Clin Imaging Sci* 2020;10:42. doi: 10.25259/jcis_72_2020